

A 120 MPC SCALE IN THE UNIVERSE

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1. Introduction

Galaxies are not distributed randomly but are concentrated within elongated filamentary chains which consist of groups and clusters of galaxies; the space between filaments is devoid of galaxies. Such distribution can be called cellular (Jõeveer and Einasto, 1978; Zeldovich *et al.*, 1982): a cell is a large low-density region surrounded by superclusters. Examples are the Northern Local Void surrounded by the Local, Coma and Hercules superclusters (Lindner *et al.*, 1995), and the Bootes void (Kirshner *et al.*, 1981) surrounded by the Hercules and Bootes superclusters. Superclusters and voids form a continuous network of alternating high- and low-density regions; the mean diameter of voids between clusters in the supercluster-void network is about $100 h_{100}^{-1}$ Mpc (Zeldovich *et al.*, 1982).

It is not clear whether superclusters and voids form a regular or irregular network. According to the classical paradigm of the formation of large scale structure the distribution of density waves is Gaussian on all scales, and thus the supercluster-void network should have a random character. The observed network was formed by density waves of a wavelength range corresponding to the scale of the network. Therefore, it was a great surprise when it was found that the distribution of high-density regions along pencil beams around the northern and southern Galactic pole is fairly regular: high- and low-density alternate with rather constant step of $128 h_{100}^{-1}$ Mpc (Broadhurst *et al.*, 1990). The regularity of the structure is so far well established only in the direction of Galactic polar caps, while in other directions the regularity is much less pronounced. In order to find the degree of the global regularity of the supercluster-void network 3-dimensional data of the distribution of high-density regions are needed. For this purpose Abell-ACO clusters of galaxies (Abell, 1958; Abell *et al.*, 1989) can be used. These clusters cover the whole celestial sphere outside the Milky

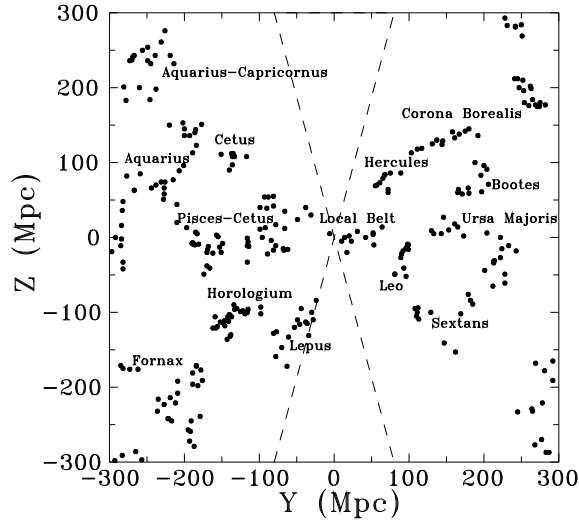


Figure 1. Distribution of clusters in high-density regions in supergalactic coordinates (Einasto 1995). Only clusters in superclusters with at least 8 members are plotted. The supergalactic $Y = 0$ plane coincides almost exactly with the Galactic equatorial plane; the Galactic zone of avoidance is marked by dashed lines.

Way zone of avoidance. Here I give a summary of our principal results, a more detailed analysis is published elsewhere.

2. Distribution of clusters of galaxies

The distribution of clusters of galaxies located in very rich superclusters with at least 8 member-clusters is shown in Figure 1 (Einasto *et al.*, 1994; Einasto, 1995; Einasto *et al.*, 1997b), see also (Tully *et al.*, 1992). This Figure shows clearly that high-density regions are separated from each other by a fairly constant intervals of $\approx 120 h_{100}^{-1}$ Mpc; in other words, they form a quasi-regular network of superclusters and voids.

We supplemented this qualitative description by a quantitative analysis, using the power spectrum of clusters of galaxies (Einasto *et al.*, 1997a). On short wavelengths the spectrum can be approximated by a power law with index $n = -1.8$. On wavenumber $k_0 = 0.05 h_{100} \text{ Mpc}^{-1}$ it has a sharp peak; this wavenumber corresponds to the wavelength $\lambda_0 = 2\pi/k_0 = 120 h_{100}^{-1} \text{ Mpc}$. On longer scales the error corridor of the spectrum is large and here the spectrum is compatible with the Harrison-Zeldovich spectrum of power index $n = 1$.

The presence of a sharp maximum in the power spectrum of matter is

the main finding of our study of the distribution of clusters of galaxies. Our result has found independent support from other data (Landy *et al.*, 1996; Gaztanaga and Baugh, 1997; Peacock, 1997; Retzlaff, 1997). Comparison with simple toy models shows that a peaked power spectrum is possible only if high-density regions form a quasiregular rectangular network (Einasto *et al.*, 1997d; Einasto *et al.*, 1997c). In this case the correlation function of objects located in high-density regions is oscillating. Evidence for an oscillating cluster correlation function has been accumulating already for some time (Kopylov *et al.*, 1988; Mo *et al.*, 1992; Einasto and Gramann, 1993; Fetisova *et al.*, 1993).

3. Comparison with CMB data

The angular power spectrum of the cosmic microwave background (CMB) has been measured by a number of teams. We compared the CMB spectrum with optical data using three models for the power spectrum: (a) a scale-free initial spectrum, (b) a double power law approximation to the cluster spectrum, and (c) a spectrum based on the observed cluster spectrum. For a set of cosmological parameters, we calculate the matter transfer function, and the matter and radiation power spectra for all three models (Atrio-Barandela *et al.*, 1997). We assume the Universe has a flat geometry. In calculations we used the package CMBFAST (Seljak and Zaldarriaga, 1996). To estimate the goodness of a particular set of cosmological parameters we calculate the parameter χ^2 for all three principal models, see Figure 2.

In Figure 3 we compare matter power spectra and temperature anisotropy spectra for our three basic models with the data. The cosmological parameters were chosen to reproduce the CMB data (Netterfield *et al.*, 1997). We see that the temperature anisotropy spectra are very similar in the range of multipoles observed in Saskatoon. In other words, the present CMB data are not sufficient to discriminate between models. The matter power spectra are also similar on short wavelengths but on medium and long scales they are very different. The scale-free model with large cosmological constant has a broad maximum at large wavenumber ($k \approx 0.01 h_{100} \text{ Mpc}^{-1}$); the maximum of the first acoustic oscillation occurs at $k \approx 0.1 h_{100} \text{ Mpc}^{-1}$ and is of rather small relative amplitude. Both scales are outside the allowed range of the observed spike in the cluster spectrum: $k_0 = 0.052 \pm 0.005 h_{100} \text{ Mpc}^{-1}$ (Einasto *et al.*, 1997a). No combination of cosmological parameters can reproduce the spike at $k = k_0$: the existence of a broad maximum is an intrinsic property of all scale-free models. Thus the observed spike is not related to acoustic oscillations in the baryon-photon plasma as assumed by Szalay (1997) but must have a different origin. On the other hand, the cluster and double power law spectra fit the observed cluster spectrum by

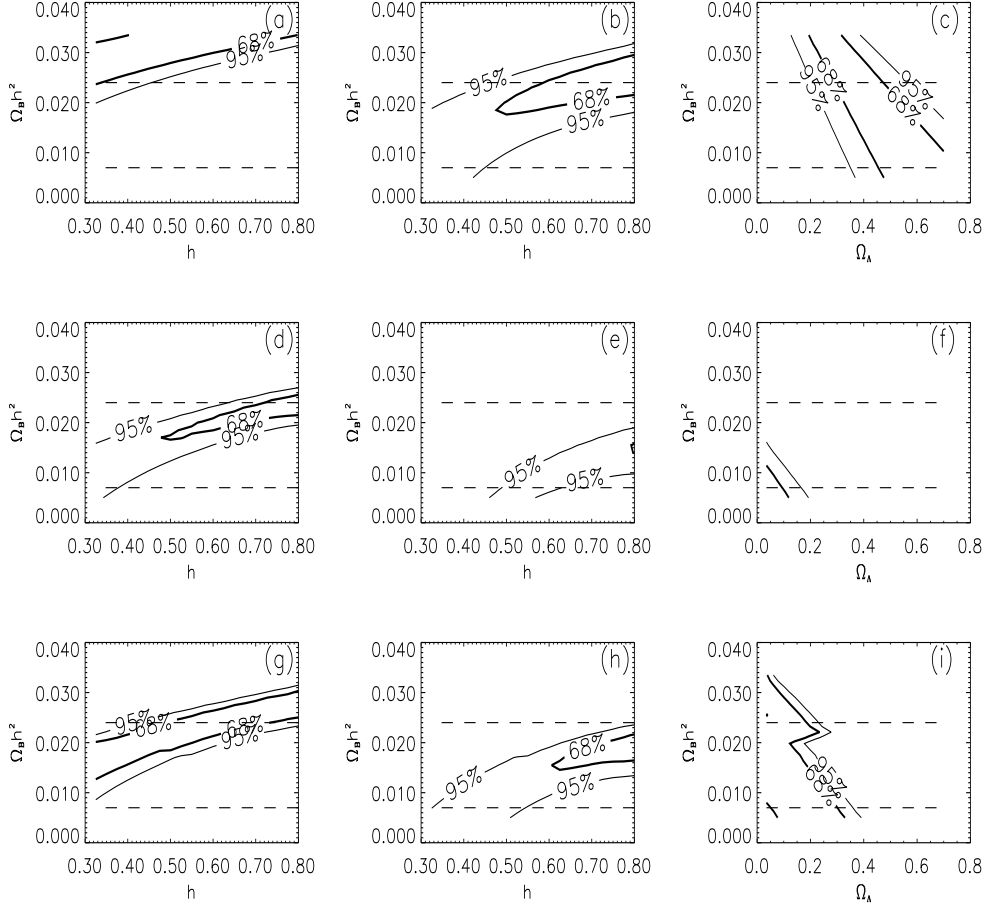


Figure 2. Goodness-of-fit contours of χ^2 at 68% and 95% confidence level. The χ^2 statistics measures the deviation of the expected temperature anisotropy amplitude of a given model from the Saskatoon data. The first row displays the results for the scale free model; the second row for the double power law model; and the lowest row for the cluster spectrum based model. In the first column we plot models with varying Hubble constant and baryon fraction for a spectral index $n = 1$ at large scales and no cosmological constant. In the middle column the same diagrams were repeated for $n = 1.2$. Dashed lines indicate the nucleosynthesis bounds. The last column displays the results for models with different values of the cosmological constant. On all these models, the age of the Universe was chosen to be 14 Gyr.

construction and reproduce the CMB data, i.e they fit equally well both datasets.

Thus the comparison of optical and CMB data brings us to the conclusion that CMB data are not in conflict with the presence of a spike in the

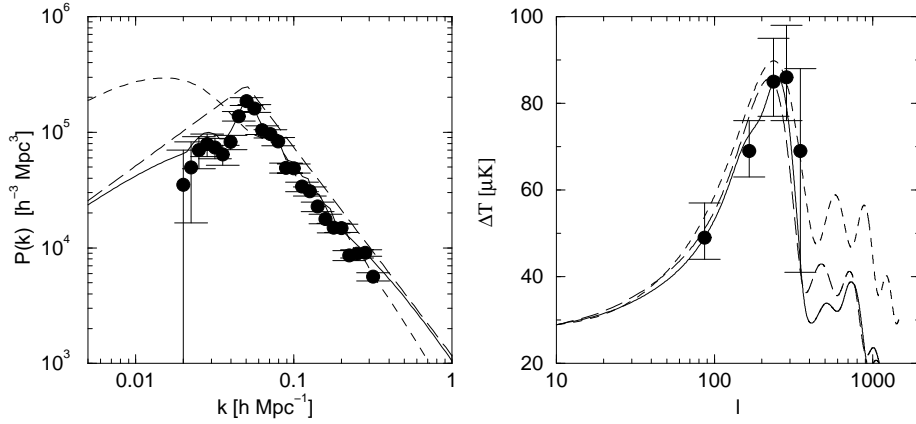


Figure 3. Comparison of matter power spectra and radiation temperature anisotropies with cluster and CMB data. Dots with 1σ error bars give the observations: the measured cluster spectrum (Einasto *et al.* 1997a) in the left panel and the Saskatoon data on CMB temperature anisotropies (Netterfield *et al.* 1997) in the right panel. The scale-free model spectra (short-dashed lines) were computed using the following parameters: $h = 0.6$, $\Omega_b = 0.07$, $\Omega_c = 0.23$, and $\Omega_\Lambda = 0.7$. The cluster spectrum (solid lines) was calculated using $h = 0.6$, $\Omega_b = 0.08$, $\Omega_c = 0.92$, and $\Omega_\Lambda = 0$; and the double power law models (long-dashed) using $h = 0.6$, $\Omega_b = 0.05$, $\Omega_c = 0.95$, and $\Omega_\Lambda = 0$. To compare matter power spectra and observations we used a bias factor $b_{cl} \approx 3$ for cluster spectrum.

matter power spectrum, and that the present combined cluster and CMB data favour models with a built-in scale in the *initial* spectrum. We repeat that a regular supercluster-void network can be formed only by a power spectrum with a sharp maximum (Einasto *et al.*, 1997d). As noted by Szalay (1997) correlated phases are also crucial to form a regular network of high- and low-density regions.

Double inflation models provide a possible scenario where the formation of a spike could have taken place. One version of a double inflation model is suggested by Starobinsky (1992). This model produces a spectrum rather similar to the initial spectrum found from data (Atrio-Barandela *et al.*, 1997). The study of the distribution of matter on large scales is of crucial importance since it could provide a direct test of more complicated models of inflation.

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